ONE DIMENSIONAL ENGINE MODELING OF SINGLE CYLINDER FOUR STROKE ENGINE FOR DIFFERENT CNG INJECTION STRATEGY

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ABSTRACT

A simulation work was conducted to compare the effect performances in the cylinder with different injection strategy using compressed natural gas (CNG). The study was based on one dimensional simulation using GT-POWER software. The dimensioning was made on a motorcycle model FZ150i with single cylinder four-stroke engine. The engine was simulated in variations injection strategy with constant speed 4000 rpm with pre-chamber added. The study is focused on characterization of in cylinder pressure and temperature of performance profile for every injection strategy. The other characteristic that has been observed are emissions of CO and NOx between using compressed natural gas (CNG) with gasoline fuel. The output data are post-processed using by the GT-POST software. The analysis of the simulation data showed the improvements in the emissions using compressed natural gas (CNG) where reduction in CO and NOx. The results also are shown that the characteristics in the cylinder pressure and temperature versus crank angle engine with constant speed 4000 rpm using compressed natural gas (CNG) with pre-chamber was added is lower than base gasoline engine.

ABSTRAK

Satu kerja simulasi telah dijalankan untuk membandingkan prestasi kesan di dalam silinder dengan strategi suntikan yang berlainan dengan menggunakan gas asli termampat (CNG). Kajian ini berdasarkan simulasi satu dimensi menggunakan perisian GT-POWER. Pendimensian ini dibuat ke atas model motosikal FZ150i dengan enjin satu silinder empat lejang. Enjin telah disimulasi di dalam pelbagai strategi suntikan dengan kelajuan malar 4000 rpm dengan pra-ruang menambah. Kajian ini memfokuskan profil prestasi pada ciri-ciri tekanan dan suhu di dalam silinder bagi setiap strategi suntikan. Ciri-ciri lain yang telah diperhatikan adalah pelepasan CO dan NOx apabila menggunakan antara gas asli termampat (CNG) dengan bahan api petrol. Data keluaran selepas pemprosesan adalah menggunakan dengan perisian GT-POST. Analisis data simulasi menunjukkan penambahbaikan di dalam pelepasan gas menggunakan gas asli termampat (CNG) di mana pengurangan CO dan NOx. Keputusan turut menunjukkan bahawa ciri-ciri tekanan dan suhu di dalam silinder melawan sudut engkol enjin dengan kelajuan malar 4000 rpm menggunakan gas asli termampat (CNG) dengan pra-ruang telah ditambah lebih rendah daripada enjin petrol asas.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The alternative fuel usage has been growing due to concerns that the reserves of fossil fuel all over the world are finite and at the early decades of this century will run out completely. Compressed Natural Gas (CNG) is one of the alternative fuel that find can be use as the vehicle fuel to replacing the gasoline (petrol) or diesel fuel. This alternative fuel was having advantages in environment and air pollution control. The exploitation of full potential of CNG as an alternative fuels is means of reducing exhaust emissions. In this study, the engine used is four-stroke engine with single cylinder used on gasoline fuel that is converted to the CNG fuel engine. The different fuel injection strategy is about injection fuel with air that through the new design of pre-chamber, where it causes the effects of parameters in engine performances and emissions. The simulation of engine modeling is based on the software of GT-Power.

1.2 PROBLEM STATEMENT

The main problem in compressed natural gas (CNG) engine with pre-chamber combustion is to achieve the mixing air and fuel with the exact quantity ratio. The other problem is the effects in single cylinder four-stroke engine performances and emissions between gasoline and Compressed Natural Gas (CNG).

1.3 OBJECTIVE

To design and simulate one dimensional model engine for different injection strategy analysis based on single cylinder four-stroke engine.

1.4 SCOPES

In order to achieve the study objective stated above, the following scopes of study have been defined:-

1. All the works are based on single cylinder four-stroke engine.
2. The operation of engine is at the same speed (4000 rpm).
3. Air-fuel mixture ratio method is using high pressure fuel injection.
4. The fuel is Compressed Natural Gas (CNG) and gasoline in simulation of GT-Power software.
5. The study is using new design of pre-chamber method of injection.
6. The simulation is to observe and analysis the parameters of speed, pressure, temperature, Indicated MEP, Brake MEP, emissions from Compressed Natural Gas (CNG) and gasoline and crank angle data.
7. The validation is from the results of different injection fuel of Compressed Natural Gas (CNG) and gasoline.

1.5 THESIS STRUCTURE

Thesis structure is briefly explanation to every chapter in this thesis. The structure of the thesis is as below:-

1. Chapter 1 - This chapter discuss briefly on the project background, problem statement, project objective, and project scope. The main purpose of this chapter is to give early understanding of the overall project.
2. Chapter 2 - This chapter includes all the information acquired regarding on the project which includes the quotes and summary from the journals, reference books and other types of article review. All of the information including the principles, explanations and parameters related to this project were shown in this chapter for future reference.
3. Chapter 3 - All the methodologies are discuss clearly in this chapter and was illustrated in flow chart for better understanding.
4. Chapter 4 - All the data collected will be further to result analysis. The data was interpreted and will be analyze detail. The simulation test result will be discussed and analyzed. The validation of the predict results against experimental results of the different injection strategy.
5. Chapter 5 - This chapter is the conclusion for the whole project and determines whether this project had achieved its objectives as stated in chapter 1. Further work such as design improvement also has been discussed in this chapter and recommendation for future project development.

1.6 FLOW CHART OF STUDY

1.6.1 Flow Chart PSM 1

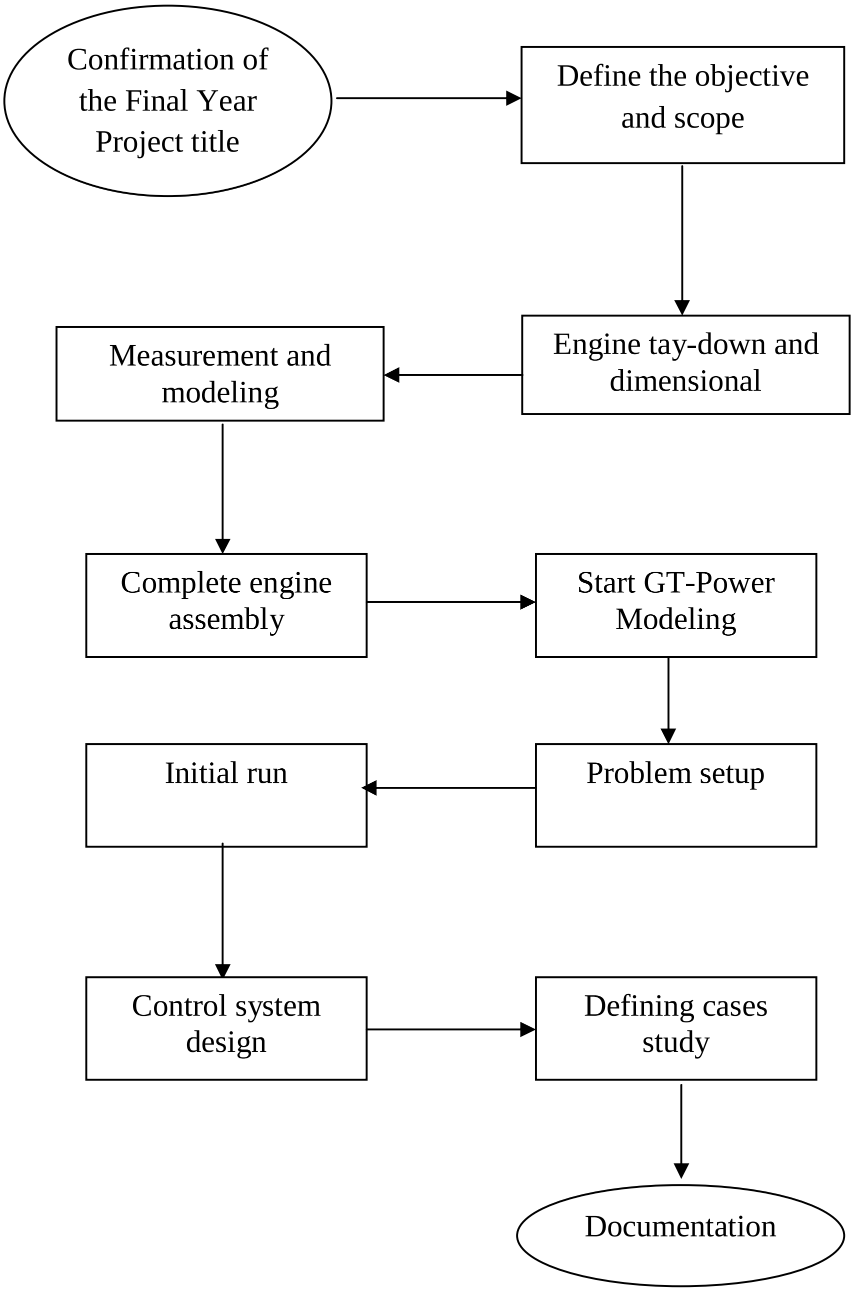

Figure 1.1 : Flow Chart PSM 1

1.6.2 Flow Chart PSM 2

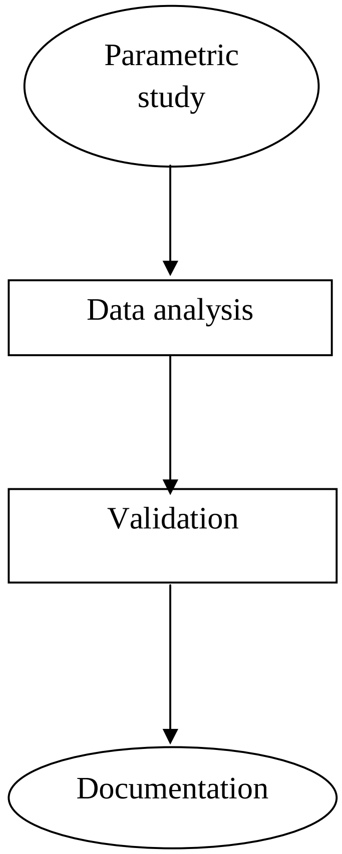

Figure 1.2 : Flow Chart PSM 2

1.7 SUMMARY

This study is proposed for the new design of injection strategy a pre-chamber engine. The design is simulated by GT-Power software where we focus in analyze to the parameters in the cylinder of engine.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter explains about basic principles in the internal combustion engine, four-stroke operation, the intake valves operation, part with new improvement and importance process in the combustion engine.

2.2 INTERNAL COMBUSTION ENGINE

2.2.1 Historical Perspective

The history of internal combustion engine is started by Abū al-'Iz Ibn Ismā'īl ibn al-Razāz al-Jazarī from 1136-1206. He described, the first suction pipes, suction pump, double-action pump, and made early uses of valves and a crankshaft-connecting rod mechanism, when he invented a twin-cylinder reciprocating piston suction pump. This pump is driven by a water wheel, which drives, through a system of gears, an oscillating slot-rod to which the rods of two pistons are attached. The pistons work in horizontally opposed cylinders, each provided with valve-operated suction and delivery pipes. The delivery pipes are joined above the centre of the machine to form a single outlet into the irrigation system. This water-raising machine had a direct significance for the development of modern engineering (Hill, D.R. May 1991 and 1996).

2.2.2 Classification Of Internal Combustion Engines

Internal combustion engines may be divided into general groups according to: the type of fuel used the method of ignition, and the number of strokes that constitute a working cycle. The three major types of fuels used are gasoline, gaseous fuels, and fuel oils. The fuel, gasoline, is in liquid form and is vaporized by being drawn through fine jets by the powerful suction of the engine during the intake stroke. At the same time, air is drawn in to mix with the vaporized fuel. Gaseous fuels include natural gas, blast furnace gas, sewage gas, and producer gas. Natural gas is the most commonly used of these and engines burning natural gas are used in locations where this fuel is plentiful and particularly as the drive units for gas compression machinery. Similarly, engines burning the other types of gaseous fuels have become common in sewage treatment plants and steel plants where gaseous fuels are readily available. Fuel oils include light oils such as kerosene and heavier oils such as diesel fuel. The heavy oil engine, commonly called the diesel engine, has many applications such as a prime mover for electrical generation in capacities up to 15 000 kW (Industries News. 2010).

2.2.3 Principle Operation Of Internal Combustion Engine

The Spark Ignition (SI) engines work on the principle of cycle of operations invented by Nicolaus A. Otto in the year 1876. The Compression Ignition (CI) engines work on the principle founded by Rudolf Diesel in the year 1892. For the engine to work properly it has to perform some cycle of operations continuously. The principle of operation of the spark ignition (SI) engines was invented by Nicolaus A. Otto in the year 1876; hence SI engine is also called the Otto engine. The principle of working of compression ignition engine (CI) was found out by Rudolf Diesel in the year 1892, hence CI engine is also called the Diesel engine.

The principle of working of both SI and CI engines are almost the same, except the process of the fuel combustion that occurs in both engines. In SI engines, the burning of fuel occurs by the spark generated by the spark plug located in the cylinder head. The fuel is compressed to high pressures and its combustion takes place at a constant volume. In CI engines the burning of the fuel occurs due to compression of the fuel to excessively high pressures which do not require any spark to initiate the ignition of fuel. In this case the combustion of fuel occurs at constant pressure. Both SI and CI engines can work either on two-stroke or four stroke cycle.

In the four-stroke engine the cycle of operations of the engine are completed in four strokes of the piston inside the cylinder. The four strokes of the four-stroke engine are: suction of fuel, compression of fuel, expansion or power stroke, and exhaust stroke. In four-stroke engines the power is produced when piston performs expansion stroke. During four strokes of the engine two revolutions of the engine's crankshaft are produced. In case of the two-stroke, the suction and compression strokes occur at the same time. Similarly, the expansion and exhaust strokes occur at the same time. Power is produced during the expansion stroke. When two strokes of the piston are completed, one revolution of the engine's crankshaft is produced.

In four-stroke engines the engine burns fuel once for two rotations of the wheel, while in two-stroke engine the fuel is burnt once for one rotation of the wheel. Hence the efficiency of four-stroke engines is greater than the two-stroke engines. However, the power produced by the two-stroke engines is more than the four-stroke engines (Khemani, H. 2008a).

2.2.4 Four-Stroke Spark Ignition (SI) Engine Cycle

In a four-stroke spark ignition (SI) engine the cycle of operations of the engine are completed in strokes of the piston inside the cylinder. The four strokes of the piston are: suction, compression, expansion or power, and exhaust. Each stroke will be described in detail.

In a four-stroke engine the cycle of the operation of engine is completed by four strokes of the piston inside the cylinder. During these four strokes fuel is once injected and burnt inside the engine and two revolutions of the crankshaft are obtained. In a four-stroke spark ignition (SI) engine the burning of the fuel occurs by the spark generated from the spark plug.

Here are the four strokes that occur inside the SI engine during its operation:

1) **Suction stroke**: At the beginning of this stroke the piston is at the top dead center or near the cylinder head and is about to move down. At this instance the inlet valve fitted in the cylinder head is opened and the exhaust valve remains closed due to the pressure difference. As the piston moves down the suction pressure is created inside the cylinder, drawing an air-fuel mixture into the cylinder. When the piston reaches the bottom most position or bottom dead center, the suction stroke ends and the inlet valve is closed.

2) **Compression stroke**: During this stroke the piston starts moving from bottom dead center to top dead center. As the piston moves up, the air-fuel mixture gets compressed into the clearance volume of the cylinder. At the end of the stroke the spark is generated by the spark plug, which causes the burning of the fuel and the release of large amounts of thermal energy. Due to this heat, high pressures are generated.

3) **Expansion or power stroke**: The large amount of pressure generated at the end of the compression stroke pushes the piston towards the bottom dead center. It is during this stroke that the actual power is produced by the engine, hence this stroke is called the power stroke and since the expansion of gases occurs during this process, it is also called the expansion stroke. During this stroke, both the inlet and exhaust valves remain closed.

4) **Exhaust stroke**: Towards the end of the expansion stroke the inlet valve remains closed while the exhaust valve opens due to the internal and external pressure difference. The piston starts moving in an upward direction and all the residual gases that are left after the expansion stroke are swept outside the cylinder and escape through the exhaust chamber. At the end of the exhaust stroke, the piston reaches top dead center position and then starts moving in the downward direction to suck the air-fuel mixture and complete the suction stroke.

In this way the cycle of operations of a four-stroke engine keeps repeating until your vehicle is running. During these four-stroke, or two revolutions of the crankshaft, the fuel is injected only once. For the maximum efficiency of the vehicle it should produce maximum power during the power stroke and produce minimum exhaust during the exhaust stroke (Khemani, H. 2008b).

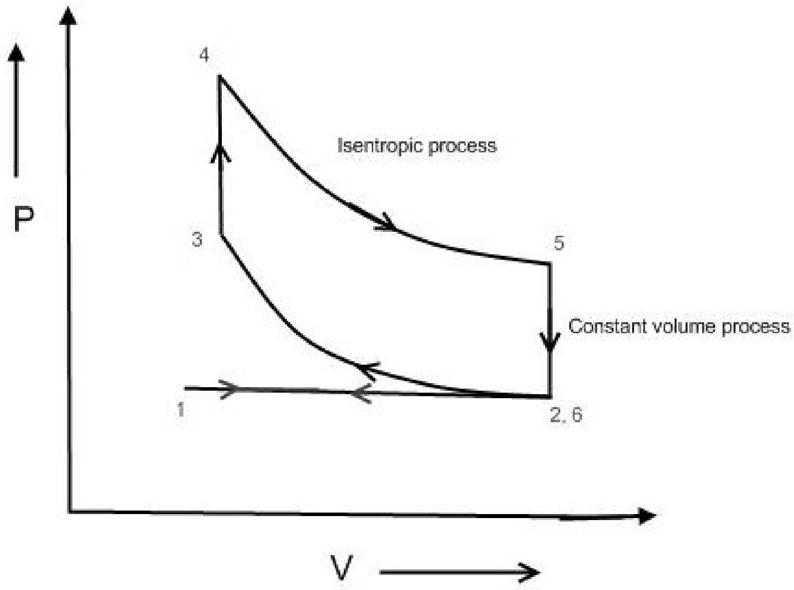

Figure 2.1 : Idealized Pressure/volume diagram of the Otto cycle.

Source : Khemani, 2008c

From figure 2.1, shown the ideal Otto cycle comprises of two isentropic (constant entropy) and two constant volume processes. The Otto cycle is an open cycle or non-cyclic process since the fresh air-fuel is mixture is inducted inside the engine during each cycle and the burnt mixture is released to the atmosphere. To understand these processes let us consider piston and cylinder engine air-fuel mixture as the working fluid. Refer the P-V diagram given at above:

1) Air-fuel intake process 1-2: During this process the inlet valve of the engine is open, the piston moves towards the bottom position inducting air-fuel mixture at constant pressure.

2) Isentropic compression process 2-3: During this process the inlet and exhaust valves of the engine remain close and the air-fuel mixture, which has been inducted inside the cylinder, is compressed to the minimum volume.

3) Combustion of air-fuel mixture at constant volume 3-4: Thereafter, the air-fuel mixture inducted inside the cylinder is combusted by the spark at constant volume; hence these engines are called spark ignition engines. This leads increase in temperature and pressure inside the cylinder.

4) Isentropic expansion process 4-5: Due to extremely high pressure, the piston is pushed again towards the bottommost position of the cylinder. It is during this process that the actual work is produced from the engine.

5) Constant volume process 5-6: During this process the exhaust valve opens and all the exhaust gases are ready to be released to the atmosphere. The pressure inside the cylinder falls drastically.

6) Exhaust process 6-1: During this process the exhaust valve is open and the piston moves upwards and removes all the exhaust gases inside the cylinder at constant pressure.

Thereafter the exhaust valve closes, the piston starts moving in downward direction, the inlet valve opens and fresh air-fuel mixture is inducted. The whole cycle is completed in four strokes of engine, hence it is called four-stroke engine (Khemani, H. 2008c).

2.2.4.1 Indicated Power (*ip*)

Power is defined as the rate of doing work. In the analysis of cycles the net work is expressed in kJ/kg of air. This may be converted to power by multiplying by the mass flow rate of air through the engine in kg per unit time. Since, the net work obtained from the p-V diagram is the net work produced in the cylinder as measured by an indicator diagram, the power based there on is termed indicated power, *ip*.

$$ip = m_a \text{ x net work} \tag{2.1}$$

where,

m_a = kg/s

net work =kJ/kg of air

ip = kW

In working with actual engines, it is often desirable to compute ip from a given p_{im} and given engine operating conditions. The necessary formula may be developed from the equation of net work based on the mean effective pressure and piston displacement.

Indicated power is then given by;

Indicated power = Indicated net work $\times$ cycles/s

$$ip = \frac{p_{im} SAnK}{6000} \tag{2.2}$$

where,

ip = indicated power (kW)

p_{im} = indicated mean effective pressure (N/ m^2)

S = length of the stroke (m)

A = area of the piston (m^2)

n = number of power strokes per minute per cylinder (rpm/2 for a four-stroke engine)

K = number of cylinders

2.2.4.2 Brake Power (*bp*)

Indicated power is based on indicated net work and is thus a measure of the forces developed within the cylinder. More practical interest is the rotational force available at the delivery point, at the engine crankshaft, and the power corresponding to it. This power is interchangeably referred to as brake power, shaft power or delivered power. In general, only the term brake power, *bp*, has been used to indicate the power actually delivered by the engine. Friction power is that part of the total power necessary to overcome the friction of the moving parts in the engine and its accessories.

The relationship between them is,

$$bp = ip - fp \tag{2.3}$$

It may also be stated that *bp* is that part of the total power developed by the engine which can be used to perform work. (Ganesan, V. 2008)

2.3 COMPRESSED NATURAL GAS (CNG) ALTERNATIVE FUEL

The use of Compressed Natural Gas (CNG or simply NG), is a clean and cheap solution for domestic use. Although it is widely available for residential use, the case with natural gas vehicles (NGV) is completely different. The advantages of natural gas (NG) as a vehicle fuel outnumber the ones of gasoline. Just to name a few, it only costs half the price of gasoline, it is safer because it is less likely to cause an explosion or fire after an accident, and engines are less prone to wear.

Although NG is much cheaper than gasoline, vehicles that use it as a fuel are not very popular. One of the major reasons is the lack of an adequate number of NG refueling stations, making long distance travel for cars and light trucks very difficult. The situation however could improve and a number of companies have recently undertaken the task to build such stations and supply fleets with significantly lower costs than gasoline. Another option is the use of a refueling appliance connected to the home's supply (Aggeliki, K. 2011).

Compressed Natural Gas (CNG) is increasingly seen as an effective alternate fuel for internal combustion engine. Based on (Bakar, R. A. 2002) benefit using CNG include:

- Higher octane number in the range of 120 to 130.
- Higher flammability compared to gasoline.
- Burns cleaner than most fuel.
- Safer; it is lighter and dissipates quickly. It ignites quickly, it ignites only when the gas to air ratio is between 5 – 15% by volume.
- Because it is a clean burning fuel, it reduces the required maintenance of vehicle.
- Plenty of reserve; there is an estimated 65-70 year supply of natural gas. Besides made from fossil, natural gas can also be made from agricultural waste, human waste and garbage.
- Cheaper per litre equivalent than gasoline, less than gasoline and 12% to 74% less expensive than diesel. In Malaysia, the CNG price is half less expensive compared to gasoline.

Table 2.1: Fuel Requirements for Various Alternative Fuels

Fuel	Storage Pressure (bar)	Fuel Storage Volume (litres)	Fuel Container Weight (kg)	Fuel Storage Temperature (Deg C)	Calorific Value NET (MJ/kg)
Diesel	1	135	30	15	42.9
Petrol	1	160	35	15	43
CNG	200	540	460	15	47.2
LPG	8	230	70	15	46.1
LNG	6	260	80	-161	47.2
Methanol	1	300	70	15	19.7
Electric	1	-	5000+	15	-
Hydrogen	300	270	950	15	119.8

Source : Stratton, 1996

The United Kingdom bus manufacturer has already evaluated eight promising alternative fuels as shown in Table 2.1. The results showed that natural gas altogether with biomass, electric and hydrogen have an opportunity to replace gasoline and diesel. There are three forms of natural gas: liquefied natural gas (LNG), liquefied petroleum gas (LPG) and compressed natural gas (CNG). Both LNG and CNG are based on methane. The difference is LNG made by refrigerating natural gas to condense it into a liquid while CNG still in the gaseous form. LNG is much more denses than CNG. Therefore, LNG is good for large trucks that need to go a long distance before they stop for more fuel. LPG is based on propane and other similar types of hydrocarbon gases. These hydrocarbons are gases at room temperature, but turn to liquid when they are compressed.

2.3.1 The Potential of CNG

CNG is the most common form on-board storage of natural gas. It is a mixture of hydrocarbons consisting of approximately 80 to 90 percent methane in gaseous form. CNG is colorless, odourless, non-toxic but inflammable and lighter than air. This is due to low energy density and compressed to a pressure of 200 to 250 bars to enhance the vehicle on-board storage in a cylinder (Aldrich and Chadler, 1997).

CNG has a low carbon (C) weight per unit of energy. As a result emissions of CO2, a greenhouse gas, can be reduced by more than 20% compared with gasoline at equivalent level of work. Moreover, there is a little wall flow fuel in the intake manifold even at low temperature because of the gaseous state of CNG. Combustion temperature for CNG fuel also tends to be lower than with gasoline engine.